Cross Enterprise Technology Development Program

Enabling Technology for Solar System Exploration Theme

C. R. Weisbin

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Exploration of the Solar System

<u>From the National Space Policy:</u>

NASA will undertake:

i.) A sustained program to support a robotic presence on the surface of Mars by year 2000 for the purposes of scientific research, exploration and technology development;

ii.) A long-term program, using innovative new technologies, to obtain in-situ measurements and sample returns from celestial bodies in the solar system

<u>From the Space Science Enterprise Strategic Plan:</u>

Science Goals:

6. Understand the nature and history of our Solar System, and what makes Earth similar to and different from its planetary neighbors

9. Understand the external forces, including comet and asteroid impacts, that affect life and the habitability of Earth

10. Identify locales and resources for future human habitation within the solar system

11. Understand how life may originate and persist beyond Earth

Summary of Key Technology Needs

Solar System missions are characterized by unique challenges

- Travel and communicate over very large distances
- Operate and survive for long periods in harsh environments (temperature, radiation, pressure)
- Conduct remote sensing, *in situ* exploration, sample acquisition and return
- Adapt to unknown and/or changing conditions

Key thrusts for near-future missions

- Establishing a virtual presence: Robotic outposts in the solar system
  - Mobility (surface and atmosphere), sensing and manipulation, visualization and data handling...toward an "interplanetary internet"
- Sampling the solar system: Tools and techniques for sample acquisition and return
- Miniaturization and revolutionary computing
- Enhanced capabilities for low-cost exploration
  - Transportation and advanced propulsion, telecommunications, power

Farther-term goals

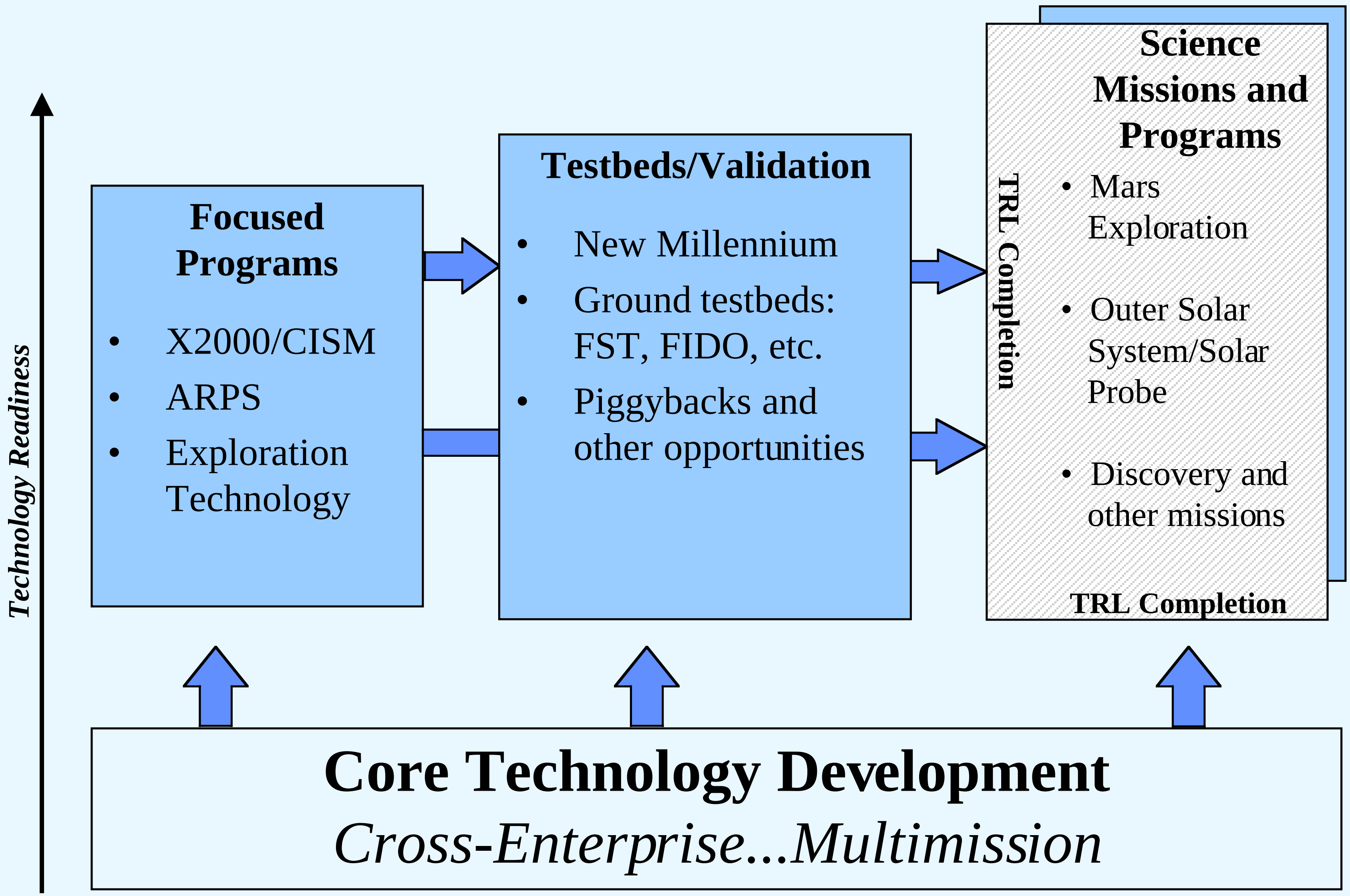
- New thrusts and initiatives for robotic networks, planetary information systems, and breakthrough propulsion concepts

Cross Enterprise Technology Development Program

Revolutionary Technology is a Major Focus

- Conceive and develop TRL 1-3 technologies
- Engage focused and other programs in co-funding for TRL 4 and above
- Develop technologies applicable to multiple enterprises
- Work with customers to advocate adoption of revolutionary technologies in revolutionary missions

Role of the Cross Enterprise Technology Development Program



Cross Enterprise Technology Development Program

Thrust Areas and Managers

- Advanced Power & On-Board Propulsion (J. Naninger)
- Atmospheric Systems and In-Space Operations (T. Nguyen)
- Breakthrough Sensors and Instrument Component Technology (T. Krabach)
- Distributed Spacecraft (K. Hartman)
- High-Rate Data Delivery (Kul.B.Bhasin)
- Micro/Nano Sciencecraft (J. Stocky)
- Next Generation Infrastructure (J. Housner)
- Thinking Space Systems (P. Norvig)
- Ultralightweight Structures and Space Observatories (C. Moore)
- Surface Systems (C. Weisbin)

CETDP Success Stories Apply to Multiple Enterprises

TECHNOLOGICAL SUCCESS STORY	HEDS APPLICABILITY	EARTH SCIENCE APPLICABILITY	SPACE SCIENCE APPLICABILITY
Sojourner & Robotic Sample Return Rovers	Surface Vehicle Mobility; Robotic Assistance to EVA		Wide Area Science; Robotic Outposts
Ka Band Communications		SATCPOM Industry & Commercial Technology	Deep Space Communications
DS-1 Remote Agent Experiment	Space Vehicle Autonomous Maneuvering	Minimal Maintenance Earth-Orbiting Systems	Deep Space On-Board Navigation
Formation Flying Control Systems	Autonomous Rendezvous Systems	Earth Orbiting Constellations	Precision Telescope Arrays
Cloud Radar ; Weather Station; < mm Wave Detectors & MOMED Mixer		Enable O3 CloudSat Mission; atmosphere OH detectors	Planetary Atmosphere & Weather Surveys
NSTAR Ion Engine & SCARLET PV Array	Ion Propulsion in HEDS Roadmap	Up to 10 KW Applicable to Earth Orbit	Continuous Thrust Deep Space Missions
Hockey Puck Sized Magnetometer Spacecraft		Spacecraft Constellations	>100 S/C Constellations
Precision Deployable & Inflatable Structures		Inflatable Shields for Large Apertures	High-Precision Telescopes

Solar Electric Propulsion Flies on New Millennium DS-1 Mission

Operation of 2.6 KWe ion engine (NSTAR) in space with advanced solar concentration PV array (SCARLET)

•First NASA use of SEP in mission

– Culmination of years of research

•First application of solar concentrator array

– Highest efficiency MBG.PV cells ever flown (23%)

– Increased w/Kg, low cost

•Opens the door for widespread use of electric propulsion

– Increased mobility

– Reduced trip times

– Smaller launch vehicles

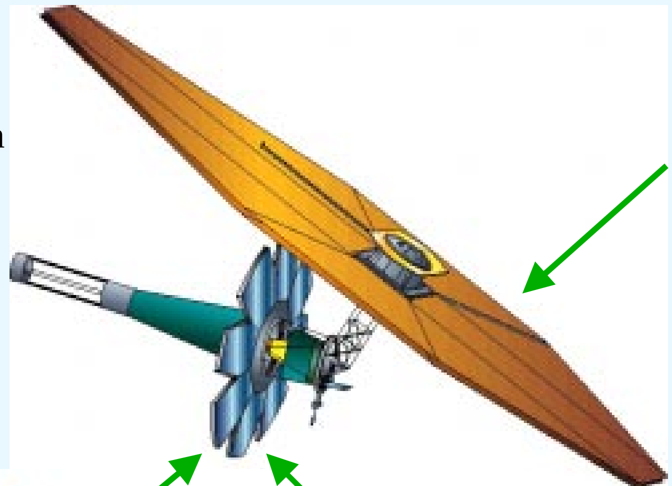
SCARLET

NSTAR

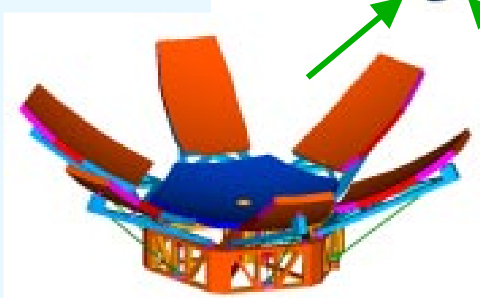
Ultra-Lightweight Structures and Space Observatories Thrust Success Story

CETDP Revolutionary Technology Has Enabled Revolutionary Missions

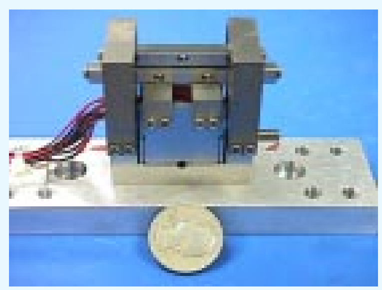
The Next Generation Space Telescope (NGST) will study the origins of galaxies at the edge of the universe. NGST will have 2x greater resolution than the Hubble Space Telescope at infrared wavelengths, and cost 1/4 as much.



Inflatable sunshield developed by CETDP will passively cool telescope to cryogenic temperatures. Inflatable structure enables 10x reduction in launch volume and 2x reduction in sunshield weight. Shown is a 1/2-scale model of the inflatable NGST sunshield.



Precision deployable telescope technology developed by CETDP will enable large apertures to be flown on smaller, lower-cost launch vehicles. Deployable primary mirror enables 3x increase in aperture size. Shown is one petal of a deployable reflector testbed with sub-micron deployment precision.



Cryogenic actuators developed by CETDP will control shape of NGST primary mirror to nanometer precision. Actuators will operate at 30 °K. Shown is prototype piezoceramic linear actuator.

Surface Systems Thrust Success Story

The Giant Rover that Could

Key Technologies

•Autonomous hazard avoidance & navigation
•6-Wheel rocker-bogie mechanism
• APXS instrument deployment
•Miniaturized rover system

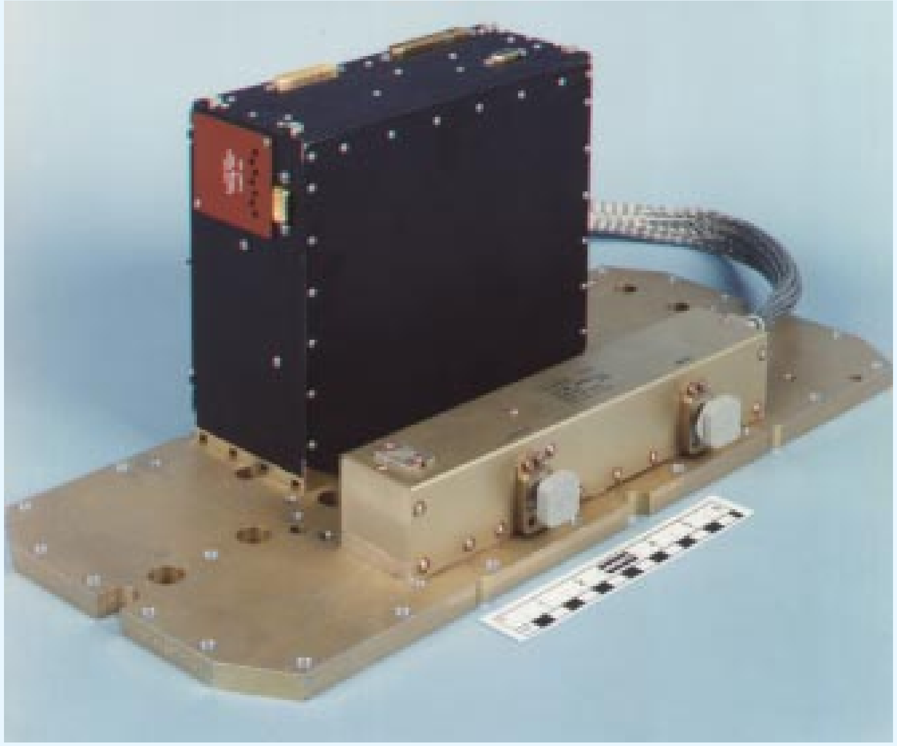
In-Space Robotics Performance

•~100 m traverse
•~15 APXS measurements
•~20 Soil mechanics measurements
•Deployment Maneuver from Lander

Recent Success Story for High Rate Data Delivery Thrust

CETDP Technology Enabled Cassini Mission Experiment

- First Ka-band TWTA for Deep Space Mission
- Enables Cassini Ka-band gravity wave experiment
- Technology doubles efficiency of 32 GHz TWTA
- Two flight TWT’s and EM TWTA produced
- GRC Impact
  - Designed TWT collector and helix circuit
  - Textured collector surfaces with unique GRC process



10-Watt, 32-GHz TWTA

Remote Agent AI Software Flies on New Millennium DS-1

•REMOTE AGENT software experiment aboard the Deep Space 1 spacecraft shows how robotic explorers of the 21st century can be built to be less costly, more capable and more independent from ground control.

•Planner and Scheduler (PS)--produces flexible plans, specifying the basic activities that must take place in order to accomplish the mission goals.
•Smart Executive (EXEC)--carries out the planned activities.
•Mode Identification and Recovery (MIR)--monitors the health of the spacecraft and attempts to correct any problems that occur.

•REMOTE AGENT successfully controlled the spacecraft for a two day period, planning and executing its actions, and recovering from simulated faults that were injected by the ground team.

CETDP PRODUCTS FOR THE SPACE SCIENCE ENTERPRISE (1 of 2 Charts)

	ORIGINS	STRUCTURE & EVOLUTION OF THE UNIVERSE	SOLAR SYSTEM EXPLORATION	SUN-EARTH CONNECTION
Atmospheric & In-Space Operations			Autonomous mini-flyers for atmospheric condition characterization for other planets	
Breakthrough Sensor & Instrument Component Technology	IR focal planes, metrology lasers and optical systems, coolers, MEMS active optics	Sum mm receivers and local oscillators, coolers, high energy focal planes, metrology lasers, IR detectors, instrument optics	In-situ physical, chemical, biological sensors, radar and lidar systems, sub mm remote sensing, IR, vis., UV focal planes w/ultralow power, adv. Optical components for remote sensing and in-situ sensors, laser spectroscopy, coolers	IR-UV focal planes, magnetometers, accelerometers, adv. Particle detectors
Distributed Spacecraft	Formation control for telescopes; communications; computer and data management	High-precision formation flying; nanometer spacecraft control		Autonomous spacecraft systems; constellations; formation control systems
High-Rate Data Delivery		Miniaturized RF communications modules; high-rate turbo codes;	In-situ communication systems for landers and rovers; in-situ protocols; reconfigurable networks	
Micro/Nano Spacecraft	Micro-electronics & GNC sensors; ultra-low-power digital circuits; radiation tolerance and design; micro-mechanical devices	Small, light,l0w-power fields and particles sensors; micro-propulsion devices	Integrated micro-power sources; advanced thermal control; extreme environment electronics (e.g. low temperature & high temperature)	Integrated micro-communication systems (short range); smart microstructures

CETDP PRODUCTS FOR THE SPACE SCIENCE ENTERPRISE (2 of 2 Charts)

	ORIGINS	STRUCTURE & EVOLUTION OF THE UNIVERSE	SOLAR SYSTEM EXPLORATION	SUN-EARTH CONNECTION
Next Generation Infrastructure	Infrastructure for analytical simulations of optical performance, cost and risk	Infrastructure for analytical simulations for deploying precision flying systems	Infrastructure for analytical simulations of autonomous robotic operations	Performance simulations and risk analysis of solar sails and miniature spacecraft
Power & On-Board Propulsion	Precision micro-newton thrusters, accompanying power systems – ultra-lightweight & long-lived	Micronewton thrusters, pulsed plasma thrusters – ultra-light long lived power systems	Advanced chemical and SEP propulsion systems, robotic power, mobile power; integrated batteries, PV arrays, vehicle power systems; integrated power and SEP systems	Advanced spacecraft power and on-board propulsion systems; integrated thin film power systems; microthrusters; pulsed plasma thrusters and power for spacecraft constellations
Surface Systems			Surface & sub-surface vehicles; multi-robot teams for exploration; high-risk access systems; robotic sampling systems; deep subsurface systems; robotic outposts	
Thinking Space Systems	On-Board Software for Spacecraft Autonomy	Intelligent system software	Remote agent software for vehicle autonomy	AI techniques and software
Ultralight Structures & Space Observatories	Large cryogenic apertures, diffraction limited optics, active wave-front control, vibration isolation, control of micro-dynamics	Large inflatable antennas, X-ray optics, large Fresnel lenses, thermal isolation, control of spacecraft charging	Solar sails, solar reflectors/concentratorslightweight solar arrays, large inflatable antennas, advanced thermal control systems	Solar sails, long-lived spacecraft systems

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Thrust Area Products Enable New SSE Capabilities

Thrusts	CETDP Products	Enabled SSE Mission Capabilities
Power & Advanced Propulsion	Advanced chemical and SEP propulsion systems, robotic power, mobile power; Integrated batteries, PV arrays, vehicle power systems; Integrated power and SEP systems	Widespread use of SEP: Shorter trip times, reduced launch vehicles, lower cost, increased payloads; Spacecraft precision formation flying; Rover, mobile surface power; Micro-thrusters
Breakthrough Sensors & Instrument Comp. Tech.	Ultralow power imagers; spectrometers (tunable laser, miniature hyper-spectral imaging, micro-mass, miniature Raman) microfluidic sample preparation; micro NMR analysis; in-situ geochronology systems; micro X-ray probes; uncooled IR detectors; MEMS seismometers and hygrometers; compact lidar systems; inflatable low-mass radar	Advanced physical, chemical, and biological in situ analysis of planetary bodies; integrated, low mass payloads for micro spacecraft; compact remote sensing payloads for long duration monitoring; subsurface exploration with in situ instruments and surface penetrating radar
High Rate Data Delivery	Miniaturized RF Communications & Network Modules; Propagate Models, High Rate Turbo Codes	Low-cost, Lightweight High Data Rate Systems; In-Situ Communications for Landers and Rovers
Thinking Space Systems	Planning & Reasoning Techniques; AI based autonomous systems	Enhanced spacecraft autonomy; improved mission operations
Surface Systems	Robotic Outposts; High-Risk Access Systems; Deep Sub-Surface Systems; Multi-Robot Systems	Robust Economical Colonies of Intelligent Robots for Planetary Exploration; rovers; subsurface systems; sample acquisition and handling; advanced robotics
Distributed Spacecraft	Formation Control, sensors, actuators, telecom, onboard computer and data management	Autonomous spacecraft systems; Constellations

Cross Enterprise Technology Development Program

Thrust Area Products Enable New SSE Capabilities (Continued)

Thrusts	CETDP Products	Enabled SSE Mission Capabilities
Micro/Nano Sciencecraft	Micro-electronics; micro-GN&C sensors; ultra-low-power digital circuits; micro-mechanical devices; small, light, low-power fields and particles sensors; micro-propulsion; integrated micro-power sources; advanced thermal control; extreme environment electronics; integrated micro-com system (short range); smart microstructures	Micro ACS; micro-propulsion and precision formation flying; science instruments; low-mass communications
Atmospheric Systems & In-Space Operations	Balloons, ballutes, parafoils, gliders, bimorphs; advanced thermal protection system analysis; aeroshells/brakes materials; automated rendezvous and docking	Autonomous mini flyers for atmospheric characterization for other planets; autonomous precision landing from orbit; hazard avoidance
Next Generation Infrastructure	Infrastructure for analytical simulations of performance, cost and risk; analytical simulations for deploying precision flying systems, autonomous robotic operations, and risk analysis of solar sails and miniature spacecraft	Collaborative engineering and science; comprehensive mission synthesis and optimized science return per dollar of cost; reduced mission risk in deployment of new technologies through early up-front accurate simulations
Ultra-lightweight Structures & Space Observatories	Solar sails, solar reflectors and concentrators, lightweight solar arrays, large inflatable antennas, advanced thermal control	Robust economical colonies of intelligent robots for planetary exploration.

Cross Enterprise Technology Development Program

CETDP Responds to Needs of Missions in SSE Strategic Plans

- CETDP has provided enabling technology to Mars sample return missions (rovers, navigation, mobility, sampling devices, etc.)

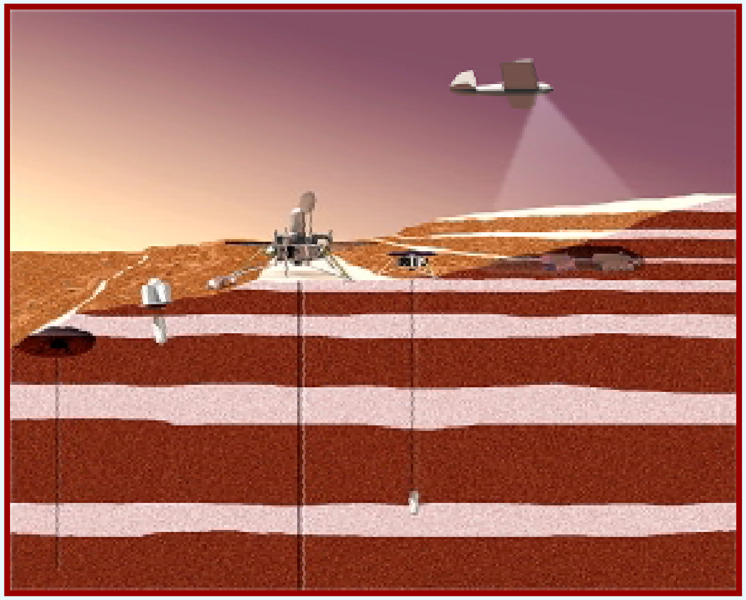
- CETDP has initiated several new FY 00 R & D tasks in support of missions within SSE strategic plans:
  - robotic outposts for Mars missions after Sample Return
  - Aerobot/balloon technology for Titan and Mars
  - In-situ resource utilization systems
  - deep subsurface exploration systems relevant to Mars and Europa

- CETDP will pursue FY 01 opportunities to respond to specific needs of Venus & Comet Nucleus Sample Return missions


BRINGING MARS TO EARTH
Life, climate, and resources
A continuous robotic presence
Mars as an element of the human experience on Earth
Paving the way for human explorers

Robotic Outposts: A New Paradigm of Exploration

Mars Polar Terrain Science Laboratory



Elements:

Surface, subsurface, orbiting and airborne investigations

Central labs for analysis/coordination

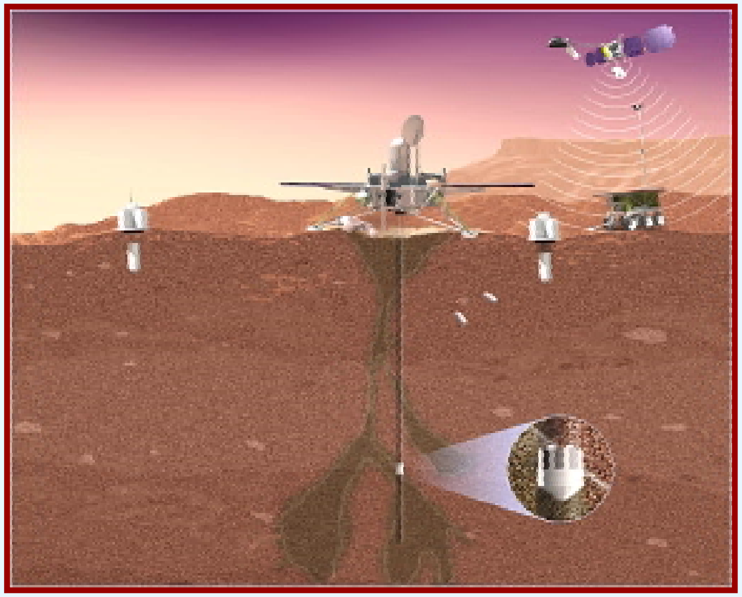
Miniature ascent vehicles

Characteristics:

Distributed robots for wide-area, 3-D exploration and sampling

Ultra-miniature, extended life, expendable/replaceable, adaptable, interactive

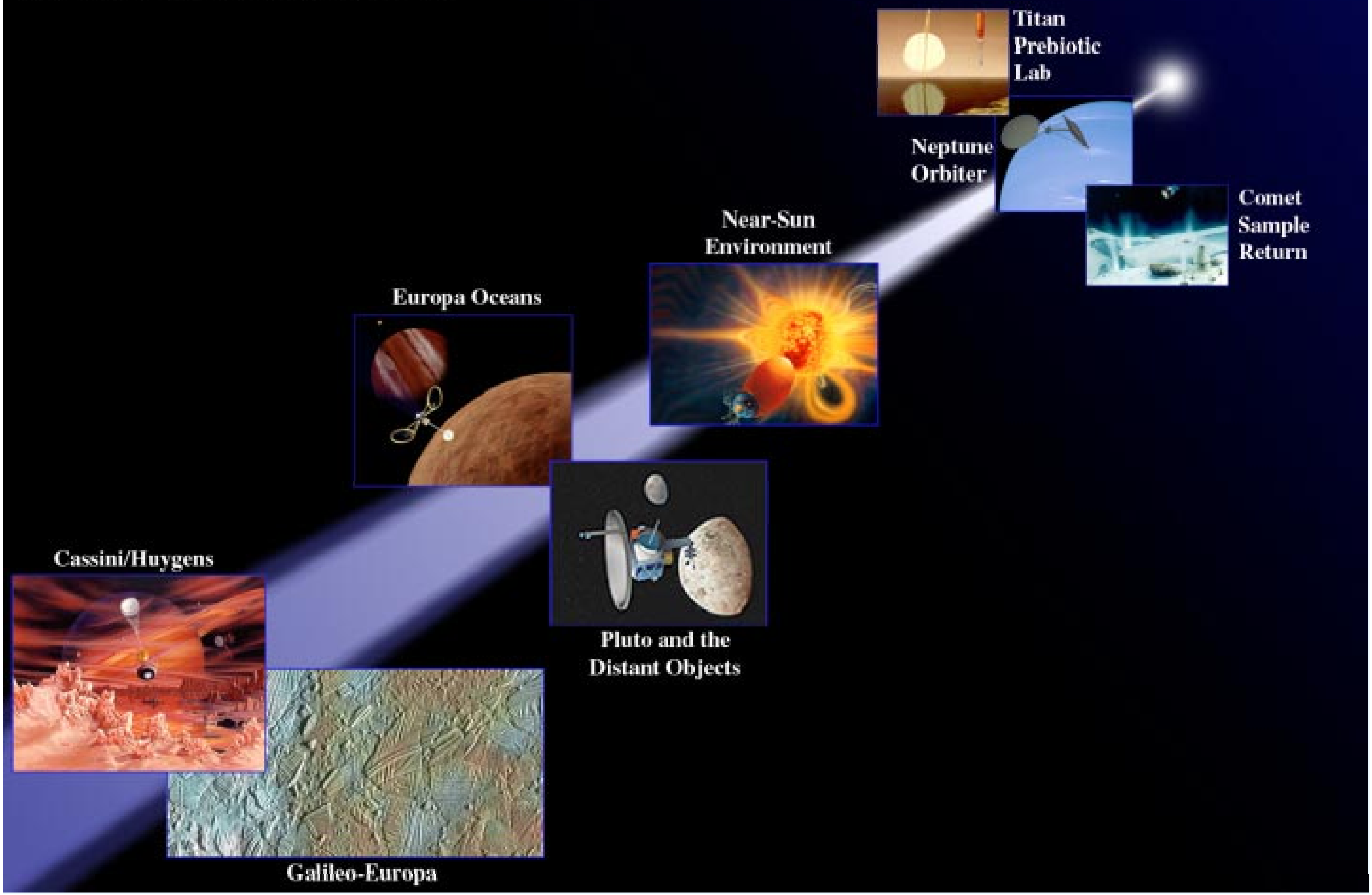
Hydrothermal Vent Science Stations



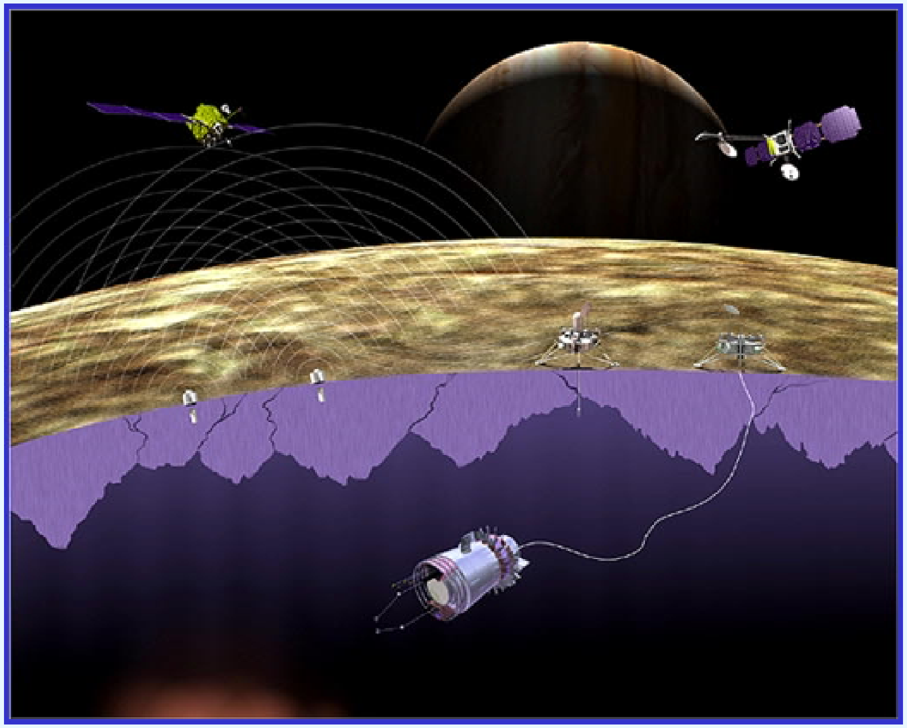
Mars Robotic Outposts and Future Sample Returns

- Surface Systems / Aerial Systems
  - Miniaturized long-life sampling rovers
  - Aerial vehicles - aerobots, airplanes
  - Subsurface sampling and mobility
- Aeroassist
  - Aerocapture and lightweight systems for Mars / Earth entry
- Advanced Power
  - Miniature radioisotope systems
  - Lightweight solar arrays for surface applications
- In situ Sensing Components, In situ Resource Extraction and Processing Components
  - Sample acquisition and handling systems
  - Miniature chemistry and geophysics labs
  - Smart sample identification and selection sensors
- Autonomous Execution and Control
  - Precision landing and hazard avoidance
  - Autonomous surface mobility
  - Interactive spacecraft and goal-directed behavior

Chemical Origins and Prebiotic Chemistry



Robotic Outposts: A New Paradigm of Exploration



Europa Ocean Science Station

Europa may one day become a target for a comprehensive “Mars-like” exploration program.

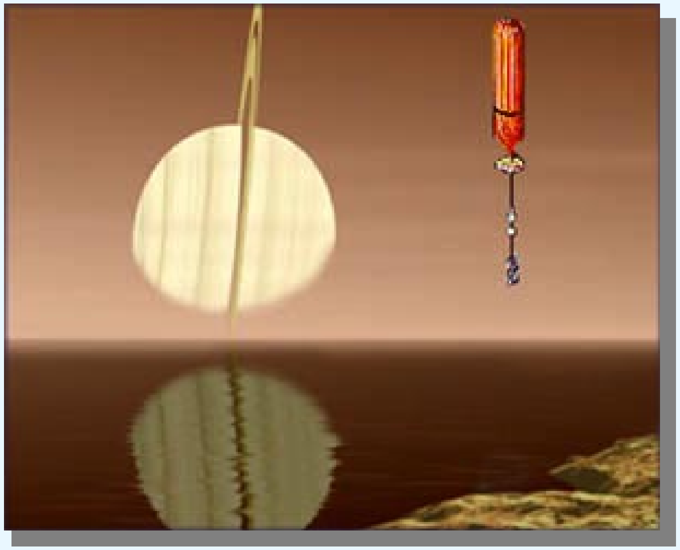
- Exploration of surface and subsurface via long-life robots
- Surface dynamics and tides
- Subsurface search for prebiotic/biotic signatures
- Interactive studies among spaceborne, surface and subsurface sensors

Europa Lander

- Advanced Power
  Advanced RPS Systems - 150W, 18% eff., 20 kg
- Advanced Propulsion
  Lightweight high performance Chemical Propulsion Systems for Descent
- In Situ Sensing Components, In Situ Resource Extraction and Processing Components
  Sample Acquisition and handling systems
  Miniaturized Organic Chemistry Lab, Miniaturized Geophysics Lab
- Autonomous Execution and Control
  Navigation - Cruise, encounter
  Landing/Hazard Avoidance, landing - accuracy <100m
  surface operations - hazard avoidance, sample acq. and handling
- Components for Severe Environments
  Radiation Hardened Electronics and Sensors
- Planetary Protection and Contamination
  Forward Contamination Control

** Values are goals derived from mission concept studies*

Titan Organics Explorer



- Science Objectives
  - Distribution and composition of organics
  - Organic chemical processes in atmosphere and surface
  - Pre-biological chemistry
  - Dynamics and global winds
  - Surface morphology
- Mission Description
  - Delta-class launch (goal)
  - Aerocapture Delivery of Titan orbiter for science and data relay
  - Rover - 10s of km

    or
  - Aerobot (condensable fluid balloon)
    - Vertical mobility - periodic descents for sample collection
    - Longitudinal motion using wind patterns

    or
  - Aerover (hybrid)
- Measurement Strategy
  - *In situ* measurements of organics in atmosphere and surface
  - Cloud chemistry and methane abundance
  - Infrared/visible imaging using atmospheric spectral “windows”
  - Altimetry of surface topography

Technology

- **Aerobot System (including low temp balloon envelopes and navigation, communication, and autonomous control)**
- **Power for Aerobot or Rover: radioisotope system or solar blankets**
- **Aerocapture at Titan**
- **Miniature *in situ* chemistry lab**
- **Sample acquisition**
- **Advanced SEP or solar sail**
- **Micro-S/C Technology**

Titan Organics Explorer

- Advanced Power
  - Solar Arrays - 150W/kg, 95 W/m^2, 10% array eff., low cost
  - Batteries - 150 Whr/kW, 150 Whr/l, 50 Ahr
  - Advanced RPS Systems - 150W, 18% eff., 20 kg
- Advanced Propulsion
  - SEP - 148 mN, 4.4 kW, 3800 Isp, 64% eff., 210 kg lifetime
  - Solar Sail - Areal density <5 gm/sq. m., >40,000 m^2 capability
- Aeroassist
  - Ballutes or Aeroshells
- Autonomous Execution and Control
  - Navigation - Cruise, encounter
  - Landing/Hazard Avoidance, landing - accuracy <100m
  - surface operations - hazard avoidance, sample acq. and handling

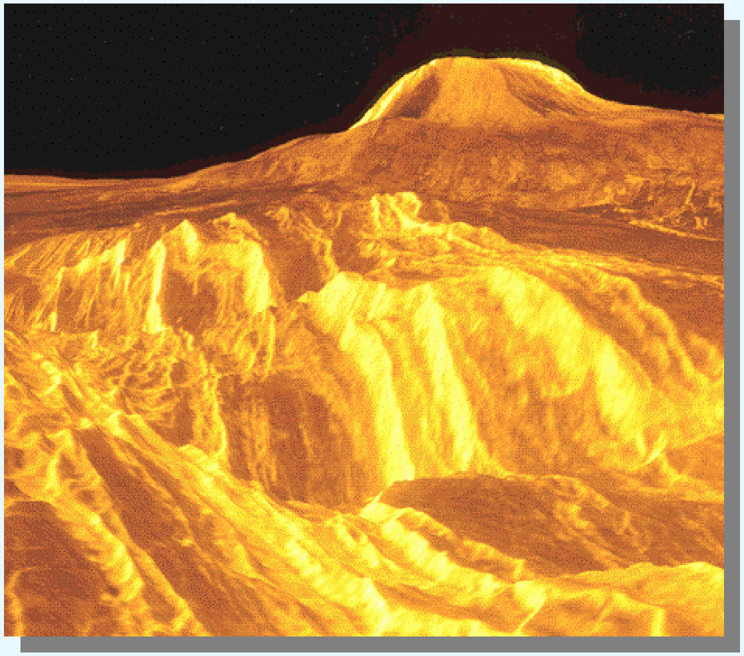
** Values are goals derived from mission concept studies*

Titan Organics Explorer
(Continued)

- In Situ Sensing Components, In Situ Resource Extraction and Processing Components
  - Sample Acquisition and handling systems
  - Miniaturized Organic Chemistry Lab
  - Miniaturized Geophysics Lab
- Surface Systems, Aerial Systems
  - Aerobots - global coverage
  - Rovers - km range
- Planetary Protection and Contamination
  - Forward Contamination Control

** Values are goals derived from mission concept studies*

Venus Sample Return



- Science Objectives
  - Return a rock sample to Earth for analysis of age and origin
  - Return samples of the Venus atmosphere to Earth for analysis of composition
  - Document sample context
- Mission Description
  - Single launch, Delta IV M+ class (3000 kg S/C)
  - Aerocapture using ballute, Aerobrake
  - Lander separates and enters using ballute
    - 90 minutes on surface
    - Balloon/rocket ascent
  - SEP for Earth return, 4 year mission
- Measurement Strategy
  - 100 g of bedrock material - from bedrock or boulder
  - Document surface sample context by imaging and spectrometry during descent - to meter scale resolution
  - One 30 mg atmospheric sample taken in lowest 20 km of atmosphere
  - One 30 mg atmospheric sample taken in the upper atmosphere below 120 km
  - Measure atmosphere species during descent and on surface

Technology

- Ballute for aerocapture and descent
- High temperature ascent balloon
- Ascent vehicle/ rendezvous
- Thermal controls
- Advanced SEP
- Sampling mechanism
- Sample handling and processing
- Lightweight science instruments
- Micro-S/C Technology

Venus Sample Return

- Advanced Power
  - Solar Arrays - 150W/kg, 95 W/m^2, 10% array eff., low cost
  - Batteries - 150 Whr/kW, 150 Whr/l, 50 Ahr
- Advanced Propulsion
  - SEP - 148 mN, 4.4 kW, 3800 Isp, 64% eff., 210 kg lifetime
- Aeroassist
  - Ballutes or Aeroshells
- Autonomous Execution and Control
  - Navigation - Cruise, encounter
  - Landing/Hazard Avoidance, landing - accuracy <100m
  - surface operations - hazard avoidance, sample acq. and handling
  - sample return - rendezvous, docking, sample transfer
- In Situ Sensing Systems, In Situ Resource Extraction and Processing Components
  - Sample Acquisition and handling systems
- Components for Severe Environments
  - High temperature Electronics
  - High temperature, acid resistant balloon materials

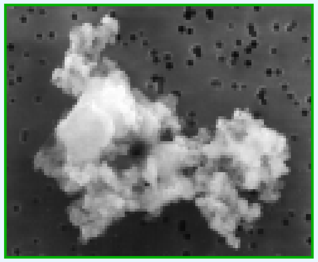
** Values are goals derived from mission concept studies*

A Decade of Primitive Body Exploration 1998 – 2008
Science and Technology Roadmap

Near-Earth Asteroid Rendezvous

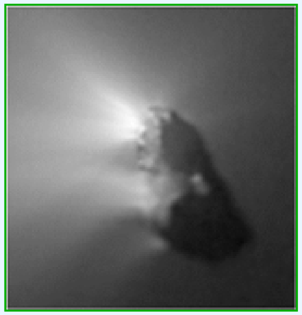
Access and Autonomy: Deep Space 1

Comet Dust Sampling: "Stardust"



Asteroid Sampling and Mobility: MUSES-C

Comet Nucleus Tour: "CONTOUR"



Comet Landing: ST4 / Champollion

Pluto-Kuiper Express

Comet Nucleus Sample Return

Comet Nucleus Sample Return

Technology

- **Comet sample acquisition and handling systems for surface or sub-surface (10-100 m) sampling at multiple sites**
- **Advanced low thrust propulsion (SEP or solar sail)**
- **Autonomous control and navigation near low-gravity bodies**
- **Aeroassist for Earth Entry**
- **Advanced radioisotope-based power systems**
- **High-efficiency solar arrays**
- **Mini/Micro organic chemistry laboratory**

- **Science Objectives**
  - **200 g of Comet Nucleus returned to Earth**
  - **Multiple sampling sites**
  - **Sub-surface sampling to _ 10-100 m**
  - **Laboratory study of primitive material, organics, and minerals**
- **Mission Description**
  - **Delta-class launch vehicles,**
  - **Mission duration of 6 to 11 yrs**
  - **Options for single spacecraft, or separable sub-spacecraft for descent, sampling, and rendezvous with return vehicle**
  - **Example Designs (Tempel 1):**
    - **SEP (14 cm NSTAR): 1060 kg L. Mass on Delta II (7925),TF of 7.1 yrs**
    - **Solar Sail (5 g/m^2): 502 kg L. Mass on Delta II (7326), TF of 10.7 yrs**
- **Measurement Strategy**
  - **Imaging/spectrometry for site selection and characterization**
  - **Sub-surface sampling using coring penetrator and tether system, surface drill, or mole**
  - **3 sites desirable**
  - **Preserve sample at acquisition temperature (150K)**

Comet Nucleus Sample Return

- Advanced Power
  - Solar Arrays - 150W/kg, 95 W/m^2, 10% array eff., low cost
  - Batteries - 150 Whr/kW, 150 Whr/l, 50 Ahr
  - Advanced RPS Systems - 150W, 18% eff., 20 kg
- Advanced Propulsion
  - SEP - 148 mN, 4.4 kW, 3800 Isp, 64% eff., 210 kg lifetime
  - Solar Sail - Areal density <5 gm/sq. m., >40,000 m^2 capability
- Aeroassist
  - Earth Entry
- In Situ Sensing Components, In Situ Resource Extraction and Processing Components
  - Sample Acquisition and handling systems , Miniaturized Chemistry Lab
- Autonomous Execution and Control
  - Navigation - Cruise, encounter
  - Landing/Hazard Avoidance - , landing - accuracy <100m
  - surface operations - hazard avoidance, sample acq. and handling, mobility
  - sample return - rendezvous, docking, sample transfer

** Values are goals derived from mission concept studies*

Cross Enterprise Technology Development Program

SSE Specific FY 00 Funded Tasks for All Thrusts

CETDP Thrust Area	Number of SSE Specific Tasks	FY 00 Funds ($K)
Surface Systems	21	12700
Ultralightweight Structures & Space Observatories	6	7695
Distributed Spacecraft	14	3400
Atmospheric Systems & In-Space Operations	7	2100
Micro-Nano Spacecraft	23	7109
Next Generation Infrastructure	12	4304
Advanced Power & On-Board Propulsion	28	5778
Breakthrough Sensors & Instrument Component Technology	30	9174
Thinking Space Systems	23	6725
High Rate Data Delivery	15	7632
TOTAL	**179**	**66617**

Cross Enterprise Technology Development Program

Highlights of FY 00 Support to SSE Theme

- Out of ~250 tasks in the CETDP FY 00 portfolio, 179 tasks have SSE as the primary or secondary customer; these tasks total ~$66 M out of ~$109 M available to the TAM's
- The SSE specific tasks represent a broad spectrum of technologies within all the CETDP thrust areas
- Most CETDP Thrust Areas show major commitment to SSE as a major customer
- Tasks applicable to SSE Theme were identified by TAM's primarily, with active participation by SSE and OSS enterprise representatives at the non-advocate reviews held for all the CETDP Thrust Areas
- TAM data about degree of applicability to SSE needs to be calibrated further in future planning

APPENDIX
Detailed SSE Specific Task Portfolio for All CETDP Thrusts

Cross Enterprise Technology Development Program

SSE Specific FY 00 Funded Tasks

Surface Systems: C. R. Weisbin, Manager

Proposal Title	Principal Investigator	Lead Center	Partners	FY00 ($K)	New or Continuing	SSE
ROBOTIC ASSISTANCE TO EVA						
Astronaut/Robot Interact. for Surface EVA	Frederickson	JSC	ARC	400	N	S
Multiresolution Mapping Using Surface, Descent & Orbital Imaging	Olson	JPL		300	N	P
ROBOTIC OUTPOSTS						
Planetary Surface Robot Work Crews	Schenker	JPL	ARC, JSC	700	N	P
Robust Hierarchical Autonomous Task Planning for Robot Colonies	Thomas/Rock	ARC	Stanford	25	N	S
A Distributed Multi-Robot Architecture for Autonomous Construction Tasks	Pendleton	JSC	ARC, CMU	150	N	S
HIGH RISK ACCESS SYSTEMS						
Inflatable Technology for Robotics	Jones	JPL		275	C	P
Nanorover Outposts	Wilcox	JPL		350	N	P
Robust Task Execution for Robotic Exploration of Planetary Surfaces	Loch	ARC		200	N	P
Accurate Positioning in Natural Terrain	Thomas	ARC	Stanford, CMU	150	C	P
Reconfigurable Robotic Surface System for All Terrain Exploration	Schenker	JPL	MIT, CMU	400	C	P
Safe Navigation of Planetary Rovers on Challenging Terrain	Seraji	JPL	CMU	250	N	P
IN-SITU RESOURCE UTILIZATION SYSTEMS						
ISRU System Miniaturization Using Micro Chemical, Thermal & EM Tech.	Wegeng	JSC		350	N	S
DEEP SUBSURFACE SYSTEMS						
Development of Active Thermal Probe for Icy Earth & Planet Environments	French	JPL		460	N	S
Robotic Subsurface Explorer	Wilcox	JPL	MIT	400	C	P
>100 m Access to Samples Deep into Martian Regolith	Briggs	ARC	JSC	300	N	P
SAMPLE HANDLING AND CURATION SYSTEMS						
Innovative Curation/Handling Systems for Future Sample Return Missions	Agee	JSC		500	N	S
Extraction of Volatiles (H,C,N,H2O, etc.) from Lunar & Mars Regolith	McKay	JSC		200	N	S
Thrust Area Reserve	Weisbin			390	N	
UNIVERSITY COLLABORATION						
National Robotics Engineering Consortium (NREC/CMU)	Weisbin/Bares	JPL	ARC/JSC/JPL	4100	C	S
Meteorite Search Demonstration (CMU)	Weisbin/Whittaker	JPL		1900	C	S
Multiple Cooperating Robots	Thomas/Rock	ARC		450	C	P
Physics Based Rover Nav & Contr (MITCollab)	Hayati/Dubowsky	JPL		450	C	P
TOTALS				12700		

Cross Enterprise Technology Development Program

SSE Specific FY 00 Funded Tasks (Continued)

Ultra-lightweight Structures and Space Observatories: C. R. Weisbin, Manager

Proposal Title	Principal Investigator	Lead Center	Partners	FY00 Cost ($K)	New (N) or Continuing (C)	SSE
Low Mass, High Performance Polymer Actuators For Tuning Membrane Structures	J. Harrison	LaRC		150	N	S
Thin Polymer Films for Space Structures and Radiation Shielding	S. Thibeault	LaRC		120	C	S
Inflatable Technology for Robotics	J. Jones	JPL	SS Thrust	150	C	P
Development of a Spacecraft Materials Selector Expert System	J. Minor	MSFC	Boeing	110	C	S
NRA	C. Moore	LaRC		1165	N	P
Gossamer Initiative	C. Moore	LaRC		6000	N	S
TOTALS				**7695**		

Distributed Spacecraft: K. Hartman, Manager

Proposal Title	**Principal Investigator**	**Lead Center**	**Partners**	**FY00 ($K)**	**New or Cont.**	**SSE**
Formation Flying Control	Hadaegh	JPL	UCLA, BYU, U. Mich.	300	C	S
Vision-Based Navigation for S/C Formation Flying	Markley	GSFC	Texas A&M Univ.	300	N	S
Centralized Tracking System Technology	Bar-Server	JPL	JPL	250	N	P
Advanced Aerobot Formation Flying	Cameron	JPL	GSFC/Wallops; Mich. St. U.; U. Col.	250	C	P
Achieving Formation Stabilization & Control w/Tethers	Quadrellia	JPL	JPL	90	N	
Distributed Optical Sensor-Based Control	Johnson	JPL	JPL	250	C	P
Mitigation of Self-Interference in Formations	Purcell	JPL	JPL	150	N	P
Precise Relative State Estimation & Control	Carpenter	GSFC	UCLA	192	N	P
Instrument and Flight System Computing for Formation Flying	Jain	JPL	U. of Kansas, U. of Iowa, JPL, GSFC	200	C	S
Self-Organizing Distributed Cooperating S/C	Mandutianu	JPL	JPL	150	N	S
Autonomous Command & Control for Formation Flight	Bristow	GSFC	AI Solutions, Inc.	124	N	
NASA/DoD University Nanosat Formation Control	Bristow	GSFC	GRC, AFRL, Stanford, JHU APL	0	C	
Program Support/Reserve (system studies, etc)	Hartman			370		
Second Solicitation	Hartman			774		
TOTALS				3400		

Cross Enterprise Technology Development Program

SSE Specific FY 00 Funded Tasks (Continued)

Atmospheric & In-Space System Operations: T. Nguyen, Manager

Proposal Title	Lead Center	Partners	FY00 ($K)	SSE
A Maneuverable, Lighter-than-Air Platform Concept for Earth Science, Planetary Science, and Astrophysics	GSFC	JHU-APL, AV, SWRI, WFF, Dartmouth	200	P
Localized Shielding Technology for Space Radiation	JSC	None	200	P
Powered Aerobots for Planetary Exploration: Innovative Concept of Aerial Deployment and Inflation	JPL	GSFC, LaRC, JPL, DRFC, WFF	400	P
Advanced Thermal Protection Systems and Materials	ARC	JSC	400	S
Spacecraft Onboard IR Networking	GSFC	JHU-APL	200	S
Robonaut for In-Space Operations	JSC	none	400	S
Innovative Balloon Buoyancy Techniques For Atmospheric Exploration	JPL	GSFC	300	P
TOTAL			2100	

Cross Enterprise Technology Development Program

SSE Specific FY 00 Funded Tasks (Continued)

Micro-Nano Spacecraft: J. Stocky, Manager

Proposal Title	Principal Investigator	Lead Center	Partners	FY00 ($K)	New (N) or Cont. (C)	SSE
Reserve	Stocky	TAM		286	C	
m/n Systems and Trade Studies	Stocky	TAM		450	C	
Next-Generation, High-Performance Micro-Gyro Development Proposal	Tang	JPL	GSFC/Gambino	390	C	P
Rad-Hard reconfigurable Field Programmable Gate Array (RHrFPGA)	McCabe	GSFC		500	C	P
Highly Integrated Micropropulsion Systems with Embedded Electronics for Micro/Nano Spacecraft	Mueller	JPL		500	C	P
CMOS, Ultra-Low-Power Radiation-Tolerant Program	Miller	GSFC	I of AµE/Maki	1,240	C	P
Microinductors: Key to Integrated Power Electronics	Brandon	JPL	GSFC/Hernandez-Pellerano	200	N	P
New Micro-Actuator Materials for Next-Generation MEMS	Shcheglov	JPL		125	N	S
MEMS Microvalve for Space Applications	Chakraborty	JPL	AFRL/Ketsdever	250	C	P
Radiation-Hardened, Mixed-Signal ASIC for Engineering Data Acquisition and Low-Level Digital Control	Armstrong	LaRC	CNU/ Hodson	300	C	P
Placeholder Task Computational Chemistry	Meyyapan	ARC		500	C	P
A CMOS, Ultra-Low-Power, Radiation-insensitive Technology 8051 Microcontroller	Benz	LaRC	UNM/Gambles/Picodyne/Giffen	300	C	P
NanoSat Structural Battery	Beaman	GSFC		158	N	P
Compact Holographic Data Storage (CHDS)	Chao	JPL		300	C	P
Sun Sensor on-a-Chip: Affordable Navigation for All Spacecraft	Gutierrez	JPL		200	N	P
Micro Spacecraft Attitude Sensor System (MSAS)	Juang	LaRC		300	N	P
High-Performance Data Compression	Miller	GSFC	UNM/Venbrux	240	C	P
CMOS, Ultra-Low-Power, Radiation-Tolerant (CULPRiT)	Culver	GSFC	UNM	350	C	P
MEMS Pumped-Liquid Cooling System for Highly Integrated Micro-Nano Sciencecraft	Birur	JPL	GSFC/Swanson	370	N	P
Highly Miniaturized, Long-Life, Alpha Particle Power Source for Electronics Operating at Extreme Temperatures in Deep-Space Missions	Patel	JPL	GRC/ Rybicki JSC/Badhwar	150	N	P
TOTALS				7,109		

Cross Enterprise Technology Development Program

SSE Specific FY 00 Funded Tasks (Continued)

**Next Generation Infrastructure: J. Hausner, Manager

FY2000 Task	Lead Center	Explore the Solar System	Sun-Earth Connection	Search for Origins	Structure and Evolution of Universe
Web-Based Knowledge Management Services for Vehicle Design	ARC	Direct relevance	Direct relevance	Indirect relevance	Indirect relevance
Pathfinder Next generation Infrastructure for Immserive Simulation	LaRC	Direct relevance	Direct relevance	Direct relevance	Direct relevance
An Expert System UML translator for Distributed Modeling Infrastructure	JPL	Direct relevance	Direct relevance	Direct relevance	Direct relevance
Virtual Mission System	JPL	Direct relevance	Direct relevance	Direct relevance	Direct relevance
Product Model Development using Data Warehousing and Data Mining Tools and Methods	GSFC	Direct relevance	Direct relevance	Direct relevance	Direct relevance
Planetary Virtual Environments	JPL	Direct relevance	Direct relevance	Direct relevance	Indirect relevance
Standard Infrastruture and Integration Process	MSFC	Direct relevance	Direct relevance	Direct relevance	Direct relevance
High Performance Information Technology Integration	JPL	Direct relevance	Direct relevance	Direct relevance	Direct relevance
Implementation of Agents and Brokers into Distributed Display Environments	JPL	Direct relevance	Direct relevance	Direct relevance	Direct relevance
Distributed Modeling Infrastructure	JPL	Direct relevance	Direct relevance	Direct relevance	Direct relevance
Model Analysis and Synthesis Infrastructure	GSFC	Direct relevance	Direct relevance	Direct relevance	Direct relevance
CFD Data Base for Space transportation Design*	ARC	Indirect relevance	Indirect relevance	Indirect relevance	Indirect relevance
* Phasing out this year					

****More quantitative analysis under way**

CETDP SSE Specific FY 00 Funded Tasks (Continued)

Advanced Power and On-Board Propulsion: J. Naninger, Manager

Proposal Title	Principal Investigator	Lead Center	Partners	FY00 ($K)	New (N) or Continuing (C)	SSE
Power Technology						
Adv, High Efficiency Solar Cell & Array Technology	Flood	GRC	AFRL, BMDO, DARPA	720	C	P
Adv Thin Film Solar Cell and Ultra-Light Array Tech	Flood	GRC	AFRL, TAMU	690	C	P
Advanced Photovoltaic Concepts	Flood	GRC	BMDO	90	C	P
Fuel Cell Systems Technology	Hoberecht	GRC	JSC, DFRC	270	C	S
Lithium Battery Technology	Manzo	GRC	AF, JPL, BMDO,TAMU	1130	C	P
Nickel Based Battery Technology	Manzo	GRC	EEI, AU	130	C	S
Aerospace Flywheel Technology	Christopher	GRC	AFRL, BMDO, NRO, ISS-JSC,TAMU, AU	990	C	S
Advanced Electrical Components Technology	Soeder	GRC		210	C	P
Power Conditioning, Control & Management	Soeder	GRC	AU	660	C	P
Low Temperature Electronics	Patterson	GRC	JPL	270	C	P
Refined Power System Env Design Codes	Ferguson	GRC		650	C	S
Power System Surfaces/ Materials	Banks	GRC	AFRL	610	C	P
NASA Aerospace Flight Battery Program	Manzo	GRC	JPL, JSC, MSFC, GSFC, AF	1400	C	P
Advanced Radioisotope Power Systems: Stirling Technology	Shaltens	GRC	Code S	50	C	P
Advanced Two-Phase Cooling	Swanson	GSFC	GRC,JPL	130	C	P
CDCs	Nainiger	GRC	Auburn, Texas A&M	1700	C	
Glennon Initiative	Nainiger	GRC		2000	C	
Propulsion Technology						
Electric Ion Propulsion	Patterson	GRC	MSFC,JPL	1400	C	P
Electric micro-Ion Propulsion	Mueller	JPL	GRC	250	C	P
Electric NSTAR Propulsion	Brophy	JPL	GRC	200	C	P
Electric Hall Propulsion	Jankovsky	GRC	BMDO,MSFC,DARPA	1170	C	P
Electric PPT Propulsion	Benson	GRC	GSFC,BMDO	600	C	P
Electric PIT Propulsion	LaPointe	GRC	JSC	120	C	P
Electric Resistojet Propulsion	Haag	GRC		162	C	P
Chemical Monoprop Propulsion	Reed	GRC	DOD	600	C	P
Chemical micro-Mono Propulsion	Parker	JPL		200	C	P
Chemical BiProp Propulsion	Schneider	GRC	DOD	398	C	P
TAM Support plus Reserve	Nainiger	GRC		678	C	
TOTALS				5778		

CETDP SSE Specific FY 00 Funded Tasks (Continued)

Breakthrough Sensors & Instrument Component Technology: T. Krabach, Manager

Proposal Title	Principal Investigator	Lead Center	Partners	FY00 Cost ($K)	New (N) or Cont (C)	SSE
Direct Detectors						
Uncooled Thermopile Broadband Detector Arrays	Foote	JPL		350	C	S
A Novel High-Performance One-Chip Digital CMOS Imager	Pain	JPL		350	C	S
High Performance, Large Format, Broad-band and Multi-color Quantum Well Infrared Photodetector (QWIP) Focal Plane Arrays for NASA Applications	Gunapala	JPL		550	C	S
IR Detector Research	McCreight	ARC		100	C	S
Ultraviolet, Visible and Infrared Imaging Using Hybrid Imaging Technology	Wadsworth	JPL		700	C	P
Radar/Submillimeter						
Space Demonstration of an Inflatable Membrane Synthetic Aperture Radar Antenna	Edelstein	JPL		300	C	S
Micromachined Membrane Diode Circuits for Astrophysics & Planetary Remote Sensing Applications	Seigel	JPL		405	C	S
MEMS Transmit/Receive Module for Thin Film Membrane Antennas	Moussessian	JPL		350	C	S
Development of a Compact Conversionless Radar System (CCRS) Using Photonic Processing	Sadowy	JPL		300	C	S
MMIC Technology	Weinreb	JPL		240	C	
High Tc Hot Electron Bolometer Mixer Fabrication	Kleinsasser	JPL		350	C	S
Transferred Substrate HBT Development for Terahertz Amplifiers & Enhanced Receiver Data Processing	Smith	JPL		160	C	S
Optics/Optical Systems						
High Efficiency Diffractive Optics	Content	GSFC	JPL, MSFC	216	N	S
Miniature Infrared Hyperspectral Imager	Reininger	JPL		180	C	P
Lasers / Photonics						
Advanced Semicond Lasers & Photonic Integrated Circuits	Forouhar	JPL		600	C	P
Hybrid Semiconductor Laser Technology Based on Planar Waveguide Circuits	Ksendzov	JPL		200	C	P
High-Efficiency Ytterbium Laser Transmitter	Bufton	GSFC		150	C	S
Mars MicroLIDAR for Wind & Dust Profiling	Menzies	JPL		150	C	S
Advanced Fiber Lasers/Amplifiers for MicroLidar	Cook	LaRC		160	N	S
High Efficiency, Eye Safe Laser for Remote Sensing	Barnes	LaRC		125	N	S
High-efficiency Oscillator/Optical Amplifier-Array Laser Transmitters	Krainak	GSFC		170	C	S
In situ sensors						
Micro Fluidic Technologies for Sample Handling for In Situ Chemical Analysis	Grunthaner	JPL		300	C	P
Microfabricated Force-Detection Spectroscopy	George	JPL		200	C	P
Microfabricated Electron & Optical Sources for Spectroscopy & Imaging	George	JPL		225	C	P
A Miniaturized LIGA Fabricated Gas Chromatograph/Quadrupole Mass Spectrometer (GC/MS) System for Space Applications	Wiberg	JPL		375	C	P
Miniature Mass Spectrometer (MMS)	Sinha	JPL		250	C	P
Prototype Miniature Local Electrode Atom Probe (Mini-LEAP)	Hunt	JPL		220	N	P
MEMS pH Sensor System for the In-Situ Analysis of Liquid Environments	Lin	JPL		150	N	S
Acoustic Micro-Sensors & Instruments using Biomimetic Detection Principles	Hoenk	JPL		198	N	S
In Situ Geochronology	Cardell	JPL		350	C	P
Microbiology NRA	Krabach			800		P
TOTALS				9174		

CETDP SSE Specific FY 00 Funded Tasks (Continued)

Thinking Space Systems: P. Norwig, Manager

Proposal Title	Principal Investigator	Lead Center	Partners	FY00 Cost ($K)	ESE
Reusable Pattern Recognizers for Solar Imagery	Michael Turmon	JPL		250	P
A Hybrid Discrete/Continuous Diagnostic Engine	Dan Clancy	ARC		520	P
Onboard Summarization and Spacecraft-Initiated Operations Technology	Dr. Jay Wyatt	JPL		200	P
Visual Methods for Small Body Exploration	Andrew Johnson	JPL		230	P
Onboard Science Analysis and Knowledge Discovery	Michael Burl	JPL		460	S
Model-based Programming Skunk Works	Mark Shirley	ARC		600	P
Model-based Monitoring, Diagnosis, and Control	Jim Kurien	ARC		690	S
Diagnosis Framework for MDS	Dan Dvorak	JPL		115	P
Object Oriented Smart Executive	Erann Gat	JPL		145	P
Adapting Coordination and Cooperation Strategies in Teams	Berenji/ Boyan	ARC		230	P
Amphion/ Meta-Amphion: High-Assurance Program Synthesis Systems	Mike Lowry	ARC		575	P
3-D Super-Resolution from Multiple Images	P. Cheeseman	ARC		700	P
Evaluating the Application of Machine Learning to Control of Advanced Life Support Systems	D. Kortenkamp	JSC		345	S
ISPP model-based control	Jane Malin	JSC		175	S
Distributed Self Commanding Robotic Systems	A. Barrett	JPL		200	P
Demonstration of Quantum Algorthims and Quantum Computing Hardware	Colin Williams	JPL		175	P
Closing the Gaps in Software Development for NASA Space Enterprises	Mike Lowry	ARC		345	S
Biologically Inspired Control for Legged Explorers	Ron Jacobs	ARC		125	P
Onboard Pattern Recognition for In Situ Science: Detecting and prioritizing Rover Science Opportunities	Eric Mjolsness	JPL		175	P
On-Board Autonomy for Rovers	R. Washington	ARC		230	P
Context-Model Based Data Typing and Data Compression Techniques for Space Applications	Pen-Shu	GFSC		115	P
Rapid Detection of Magnetospheric Boundaries using Neural Network Analysis Techniques Applied to the IMAGE Mission	Jim Green	GFSC		60	P
TAM Suport/Reserve	Peter Norvig	ARC		65	S
TOTALS				6725	

CETDP SSE Specific FY 00 Funded Tasks (Continued)

High Rate Data Delivery: K. Bhasin, Manager

Proposal Title	Principal Investigator	Lead Center	Partners	FY00 Cost ($K)	SSE
SiGe RF Solid State Amplifier	Ponchak	GRC	JPL	525	P
Acquisition, Tracking, and Pointing (ATP) Technologies for Optical Communications	Hemmati	JPL		640	P
Efficient Component Technologies for Laser Communications	Hemmati	JPL		540	P
Dynamic Signal Processing Technologies for Optical Communications	Arabshahi	JPL		150	S
MCAS1 for Mars'03 Applications (i.e., airplane micromission, lander, rover, ASAP relay orbiter)	Agan	JPL		780	P
Micro Communications and Avionics System Prototype Development for Mars'05 Microprobe Applications (MCAS2)	Agan	JPL		170	P
Low Cost Dual Navigation and High Rate Transceiver Technologies	Srinivasan	JPL		250	S
Low Cost Multi-Gbps Transceiver Technologies	Gray	JPL		450	S
Micro opto-electronic mm-wave oscillator on a chip	Yao	JPL		250	S
Smart Wireless Sensor Communications and Network Development	Jedrey	JPL		300	P
Cooperative Communications for Remote Exploration	Wang	JPL		255	P
Radiowave Propagation Characterization for high rate space communications	Golshan	JPL		285	P
High Rate Imagery Processing and Delivery (HRIPD)	Garengnani	GSFC		1080	
Optical Phased Array Development		MSFC		50	P
CSC	Bhasin	GRC	Umd, Florida	1105	S
TAM Support	Bhasin-TAM			110	
System Studies and Analyses	Bhasin-TAM			250	
Reserve	Bhasin-TAM			442	
TOTALS				7632	